HEAT RESISTANCE OF INNER ARC LAMP GLOBES

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"Heat Resistance of Inner Arc Lamp Globes."

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Preface.

The object of this thesis is to determine the various qualities and characteristics of heat-resisting glass used in inner arc lamp globes, in order to place the testing of these globes on a fixed basis.

As there has been no references available on tests of this nature, the report is practically void of a bibliography.

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PART I.

General Problem.

In order to place the testing of inner arc lamp globes on a fixed basis, the following method of test has been worked out.

What we shall term "heat resistance" is that property of the globe to withstand fairly high temperatures without deformation, and also that property of withstanding sudden changes of temperature without cracking or breaking. The latter characteristic is the one which is brought into action when the outer globe is for any reason off, and rain strikes the inner globe.

The quality of withstanding sudden changes of temperature depends upon a constant, characteristic of the chemical composition, annealing and tempering of the glass, and the following variables:

Thermal Conductivity

Ruptural Strength

Thickness of Glass

Coefficient of Expansion

These quantities can be equated as follows:

$$G = \frac{K \times C \times S}{T \times E}$$

Where:

G = The heat resistance of the globe

K = A constant depending upon the quality of glass

S = Ruptural strength

E = Coefficient of expansion

C = Thermal conductivity

Tests were made on two different makes of glass; the Macbeth-Evans Thermo-Glass, and the Phoenix Heat-Resisting Glass. The above variables were measured or calculated for each globe and from them the necessary constant K was solved for. This constant K will be a true measure of the relative values of the globes as heat resisting, as the other quantities which have been removed from G also have values for other reasons than heat resistance. The thickness and tensile, or ruptural strength insure lesser breakage in handling. The coefficient

of expansion and thermal conductivity prevent undue strains from the method of holding the globe in place.

Since the measurement of each variable is a problem in itself, they shall be taken up separately, and combined finally to give the desired result.

PART II.

Measurements of:-

(A) Coefficient of Expansion

(B) Heat Resistance

(C) Thermal Conductivity

(D) Ruptural Strength

A.

Measurement of, Coefficient of Expansion.

The linear expansion of glass usually will be found approximately proportional to the change in temperature, that is to say, if the values of L_t, (length at any temperature t) are plotted as ordinates with the corresponding values of t as abscissae, the result will be a curve, though the curvature is very slight. In general it is found that L_t may be very closely represented by an expression of this form;

$L_t = L_o(1+at+bt^2+ct^3+---------)$ where a, b, and c are constants, and t the temperature on the Centigrade scale. The number of constants necessary increases with the temperature range over which it is attempted to work, and with the accuracy desired, also varying with different substances. For small differences, the constant a is sufficient, where

a is the coefficient of expansion, and its value is evidently;

$$a = \frac{L_t - L_o}{L_o t}$$

As will be seen from the data, the coefficients are never large, and very refined experimental methods are necessary to determine them very accuragely.

The apparatus used in this case, as shown in the accompanying photograph, consists of two microscopes, mounted on a heavy bar on which they could be moved. These microscopes were arranged so that they could be focused on two lines drawn on the glass, the coefficient of expansion of which was to be measured. A small oven lined with asbestos was used to heat the glass. A thermometer was inserted into the oven to obtain the temperature, while bunsen burners were used to heat the oven.

The method used is as follows:-

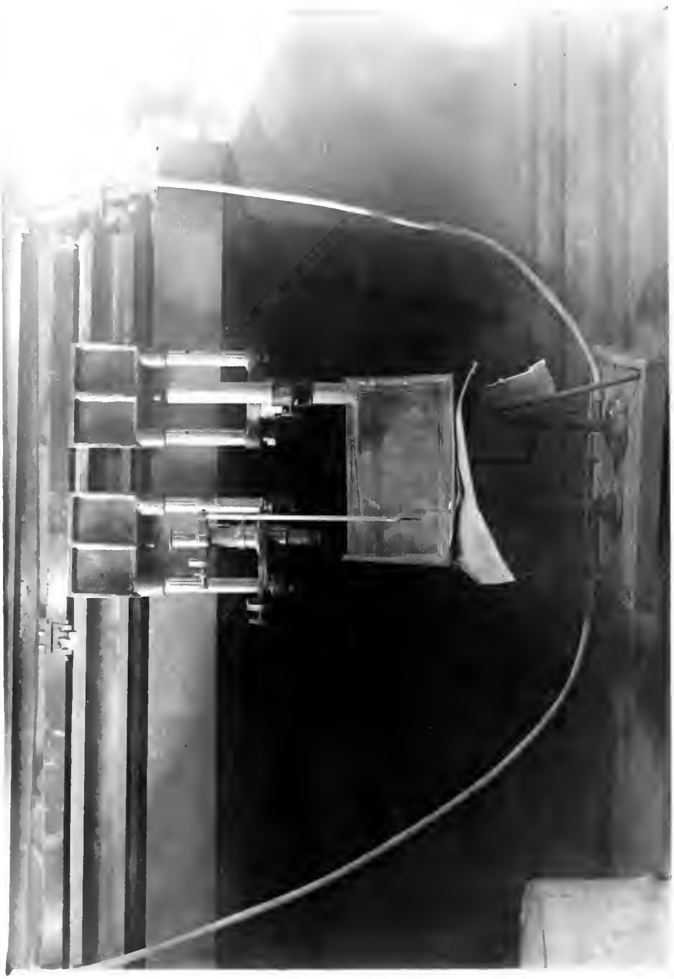


FIG. 1.

A mark or line was ruled on each end of the glass bar. The distance between these marks was measured by the use of the comparimeter and the standard meter bar. (A photograph of the comparimeter is also shown). The comparimeter is an instrument with two microscopes which were focused on the ruled lines on the glass, and then moved over the standard meter by means of an adjusting screw and a rider, on which the microscopes are mounted. The length between the marks on the glass was then read on the standard meter bar. This gave the initial length L_o of the glass. The sample was then placed in the oven, which had small openings in the top, over the lines which were ruled on the glass, and the microscopes were focused on the lines. The oven was then heated very gradually and the temperature, also the expansion of the glass was noted at the same time. The readings were taken about every twenty degrees. The

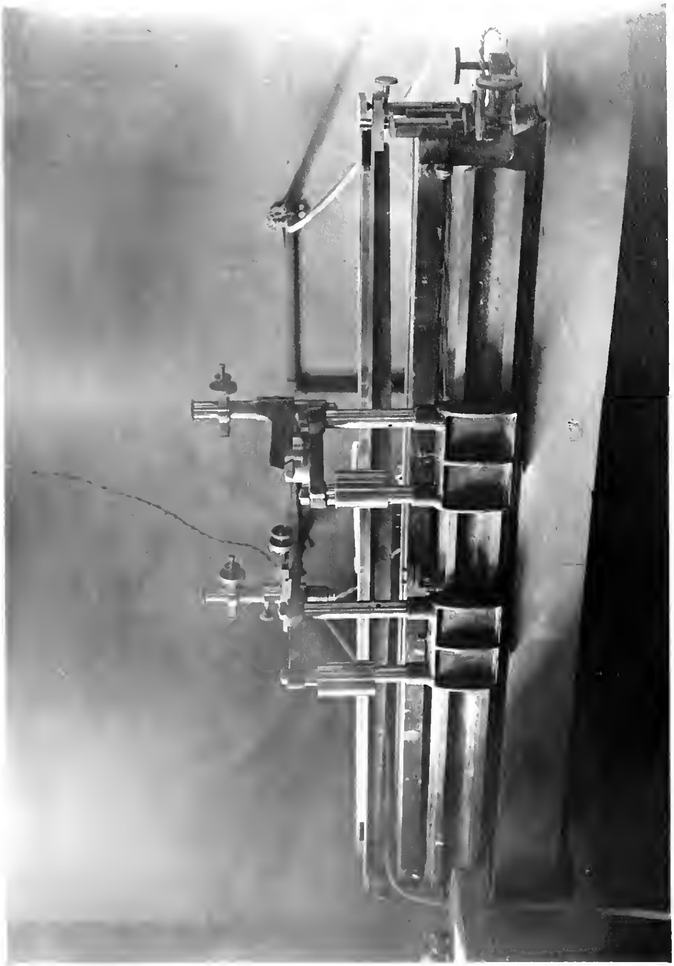


FIG. 2.

expansion $(L_t - L_o)$ was noted, and read directly by means of a micrometer on the microscope setting. Readings were taken up to about 180° degrees Centigrade. The above readings gave the necessary values of t, t_o and L_t, L_o to substitute in the formula;

$$a = \frac{(L_t - L_o)}{L_o t}$$

The specimens used in the test were about 18 cm. long and 2.5 cm. wide. The results obtained were as follows:-

Globe #1.

t	$(L_t - L_o)$	T	L_o	$\alpha \times 10^{-7}$
Temp.	Exp.-mm.	Temp Diff	cm.	
23.5	0	0	19.3	----
91.0	18.5 $\frac{1}{200}$	67.5	"	7.1
113.0	6.6 "	22.0	"	7.5
128.0	4.65 "	15.0	"	8.0
146.0	5.31 "	18.0	"	7.65
172.0	7.15 "	26.0	"	7.15
			Av	7.43 $\times 10^{-7}$

Globe # 2.

23.5	0	0		----
80.0	14.17 $\frac{1}{200}$	56.5	18.2	6.9
105.0	4.9 "	25.0	"	5.4
129.0	5.46 "	24.0	"	7.0
141.0	3.54 "	12.0	"	8.1
160.0	4.55 "	19.0	"	6.6
180.0	5.16 "	20.0	"	7.1
190.0	3.14 "	10.0	"	8.65

Av. 7.11 $\times 10^{-7}$

Globe # 3.

t	$(L_t - L_o)$	T	L_o	$a \times 10^{-7}$
Temp.	Exp.-mm.	Temp. Diff	cm.	
23.5	0 $\frac{1}{200}$	0	16.5	5.6
100.0	14.0 "	76.5	"	6.3
120.0	4.11 "	20.0	"	5.5
140.0	3.6 "	20.0	"	5.4
160.0	3.53 "	20.0	"	7.3
178.0	4.28 "	18.0	"	
			Av	6.02×10^{-7}

Globe # 5.

23.5	0 $\frac{1}{200}$	0	19.5	$a \times 10^{-7}$
101.0	0 "	0	"	
132.0	7.18"	31	"	5.95
151.0	4.61"	19	"	6.22
174.0	7.00"	23	"	7.8
185.0	3.33"	14	"	6.1
			Av	6.52×10^{-7}

Globe # 4.

t	$(L_t - L_o)$	T	L_o	$\alpha \times 10^{-7}$
Temp	Exp--mm. $\frac{1}{200}$	Temp. Diff	cm.	
23.5	0	0	18.7	
83.0	15.1 "	59.5	"	6.9
113.0	7.26"	30.0	"	6.5
141.0	7.44"	28.0	"	7.1
171.0	9.00"	30.0	"	8.0
185.0	3.83"	14.0	"	7.3

Av. 7.7×10^{-7}

B.

Measurement of Heat Resistance

"Heat Resistance" is an arbitrary term which we used to denote that property of the globe, which enables it to withstand fairly high temperatures without deformation and withstanding sudden changes of temperature withoug cracking or breaking.

The value of the "heat resistance" of the individual globe can be determined directly by subjecting it to known temperatures and chilling a portion of it with a fixed quantity of water at a known temperature. The "heat resistance" quality will be proportional to the difference between the temperature of the glass when the glass fails, and the temperature of the water. By the proper selection of the unit of "heat resistance" this quantity can be expressed directly as this temperature difference.

The globe was placed in an ordinary

electric oven, and heated. At regular intervals, the globe was chilled by opening the oven door, and dropping from five to ten drops of water upon the globe. This was kept up, until the globe failed by cracking. The oven temperature was read by means of an ordinary pyrometer. The temperature of the water was noted, and the "heat resistance" expressed directly in terms of the difference of temperature of the water which remained at constant temperature and the temperature of the globe when it failed. Failing of the globe was denoted by the temperature at which the first crack was noticed.

Two preliminary tests were made upon Macbeth-Evans, Thermo-Glass. On the first test, we started to drop water at 300 F., chilling the globe at every 40 degrees temperature rise of the globe up to 460 degrees F., then chilled the globe at every 20 degrees temperature rise. The globe cracked at 500 degrees F., Temperature of water, approximately 60 degrees F.

On the second test, we started to

drop water at 300 degrees F., chilling the globe at every 40 degree temperature rise, up to 400 degrees F., then chilling it at every 20 degree temperature rise. At 460 degrees F. a slight crack appeared at the top, at 480 degrees it cracked at the middle. We kept increasing the temperature, the globe cracking slightly every time we chilled it. At 690 degrees F., at which temperature we stopped, the globe was badly cracked along the side the water struck it. This shows what an enormous temperature the globe will stand, as we undoubtedly could have increased the temperature much more without destroying the globe.

Regular tests were made upon five different globes. Globes # 1, # 2, # 3, and # 4, are made of Phoenix Heat-Resisting Glass; # 5, is made of Macbeth-Evans Thermo Glass.

In each case the globe was chilled at each 20 degree F. temperature rise.

Globe # 1.

Started chilling-300° F. Globe cracked-480° F.

Average temperature of water = 68° F.

Heat resistance 480° - 68° = 412.

Globe # 2.

Started chilling-200° F. Globe cracked-540° F.

Average temperature of water = 66° F.

Heat resistance 540° - 66° = 474.

Globe # 3.

Started chilling-300° F. Globe cracked-540° F.

Average temperature of water = 70° F.

Heat resistance 540° - 70° = 470.

Globe # 4.

Started chilling-300° F. Globe cracked-500° F.

Average temperature of water = 72° F.

Heat resistance 500° - 72° = 428.

Globe # 5.

Started chilling-300° F. Globe cracked-520° F.

Water = 73° F. Heat resistance 520° - 73° = 447.

C.

Measurement of Thermal Conductivity

By thermal conductivity of a substance is meant, the rate at which heat is conducted thru the substance, i.e. its ability to conduct heat.

The absolute thermal conductivity of glass has been determined by several independent methods, of which the best known are probably the following.

The "divided bar" method, in which a rod is cut in two and the distribution of temperature down the whole bar is studied (a) when the cut ends are in intimate contact, (b) when a plate of badly conducting substance is interposed between them.

In Voigt's method, one surface of the plate is maintained at constant temperature by a current of cold water flowing over it. The other surface is exposed to hot

water in a calorimeter. The hot water is thoroughly stirred, and from its rate of cooling the amount of heat transmitted thru the plate is determined.

Paalhorn, using the well known three plate arrangement due to Christianson, has determined the conductivity of glass in terms of that of air. Lees has determined the conductivity of glass and other bad conductors by means of a disk method in which the heat energy transmitted is measured electrically. The disk methods referred to are very convenient for comparing the thermal conductivities of two substances, particularly if the substance is available in small quantities only. In all these methods, with the exception of Voigt's it is usual to secure good thermal contact between the plate of copper and the plate of substance being tested by interposing a thin layer of glycerine or mercury. Since the flow of heat is in a direction per-

pendicular to the surface of this film of foreign matter, the presence of the latter must introduce a thermal resistance which is difficult to eliminate. This is the serious objection of the method when an exact determination of the absolute thermal conductivity is required.

The method finally adopted is a modification of Voigt's method. A picture of the apparatus is shown. The globe was supported inside a galvanized pail. Cold water is constantly encircling the outside of the globe, while the inside is filled with warm water. A glass plate in which two holes were cut, covers the globe. The top of the globe is ground so that a water-tight fitting was made. A little vaseline on the top of the globe prevented it from sliding, and gives good contact. Through the small hole in the glass plate, a thermometer was placed, which measured the temperature of the water inside the globe. Through the larger hole in the center

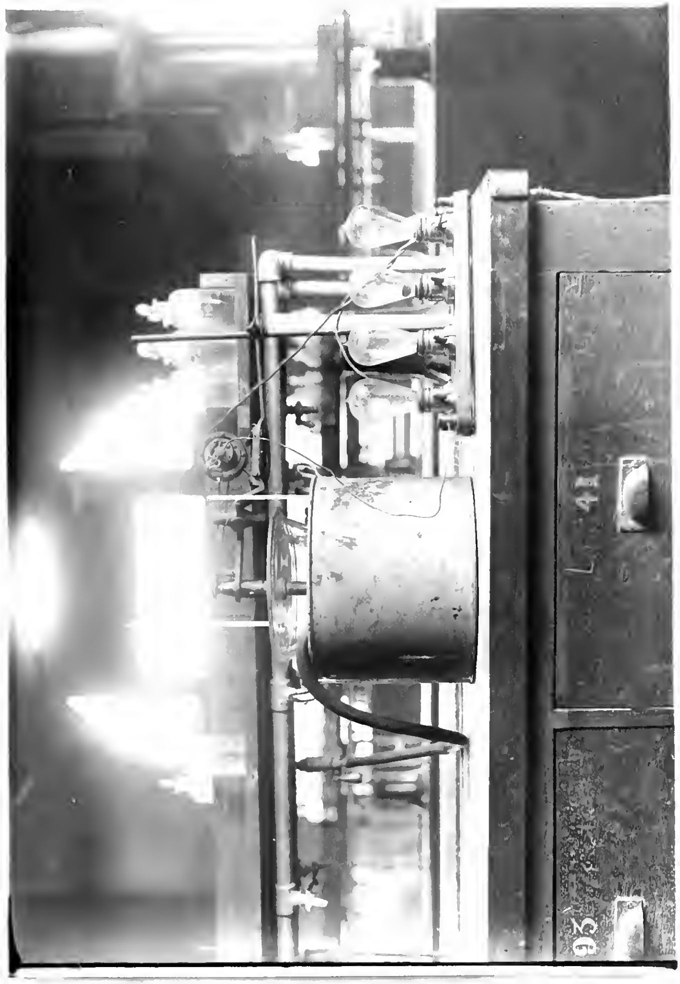


FIG. 3

of the plate, the stirring apparatus was placed. Both fittings were made tight by means of rubber stoppers. The stirring apparatus consisted of a series of small paddles attached to a shaft, which was revolved by means of a small motor. This arrangement kept the water well stirred, and therefore the actual temperature of the water could be obtained. The motor gave a desirable speed when it was connected to a 110-volt lamp socket with about three lamps in series with it.

Two runs were taken on each globe. The rate of cooling of the warm water inside the globe was determined. The temperature of the warm water inside the globe, and the cold water outside the globe was obtained at minute intervals. The weight of the water inside the globe was also obtained. From this data the thermal conductivity was calculated. Curves were plotted for each run, with time as abscissa, and $(t_2 - t_1)$ as ordinates, where t_2 is the temperature of water inside the

globe, and t_1 is the temperature of water outside the globe. The dotted curve is plotted with the data as it was taken. The full line curve represents the same data transferred to the same starting difference of temperature, or $(t_2 - t_1)$ equals 45 in each case. This was done to obtain the relative difference in conductivity, as this method isonly one of relative values. Subtracting the initial and final $(t_2 - t_1)$, and multiplying by the weight of water inside the globe, and the time, we get the B.T.U. transmitted. This is expressed in B.T.U.'s per hour, by multiplying by 3 since the time of run was 20 min., or 1/3 hrs. Divide the B.T.U./hr. by the average $(t_2 - t_1)$, and the result is a constant, denoting the thermal conductivity per sq.ft. per degree.

To obtain the average $(t_2 - t_1)$ the area underneath each curve was measured with a planimeter, and this area divided by the abscissa, to obtain the average ordinate. The $(t_2 - t_1)$

corresponding to the average ordinate in inches, represents the average $(t_2 - t_1)$.

The following tables is a result of the tests.

Globe # 1. Test # 1.

t_2	t_1	$(t_2 - t_1)$	Time, min.
60.0	16.5	43.5	10:51
56.0	16.2	39.8	10:52
53.2	15.8	37.4	10:53
58.0	15.3	35.5	10:54
48.3	15.2	33.1	10:55
----	----	----	10:56
44.0	15.0	29.0	10:57
42.1	14.7	27.4	10:58
40.3	14.5	25.8	10:59
38.8	14.5	24.3	11:00
37.4	14.5	22.9	11:01
36.0	14.0	22.0	11:02
34.8	14.0	20.8	11:03
----	----	----	11:04
32.0	13.8	18.2	11:05
30.8	13.5	17.3	11:06
29.8	13.5	16.3	11:07
28.8	13.5	15.3	11:08

Degrees, water cooled, from curve, $= 45.0 - 13.5$

$= 31.5$

Weight of water in globe $= 6$#.

Time of run 20 min, 1/3 hr.

B.T.U./ hr. $= 31.5 \times 6 \times 3 = 567$

Area, inclosed by curve $= 19.45$ sq.in.

Length of abscissa $= 6.32''$

Therefore, average ordinate $= 3.08'' = 24.2$ degrees

Therefore, thermal constant $= 567/24.2 = 23.4$

Globe # 1. Test # 2.

t_2	t_1	$(t_2 - t_1)$	Time, min.
67.0	15.0	52.0	4:26
63.0	16.0	47.0	4:27
59.5	14.	45.5	4:28
56.0	13.5	42.5	4:29
53.0	13.0	40.0	4:30
50.5	13.0	37.5	4:31
48.0	13.0	35.0	4:32
45.5	12.5	33.0	4:33
43.5	12.0	31.5	4:34
41.5	12.0	29.5	4:35
39.5	12.0	27.5	4:36
38.0	12.0	26.0	4:37
36.5	12.0	24.5	4:38
35.0	12.0	23.0	4:39
33.8	12.0	21.8	4:40
32.5	12.0	20.5	4:41
31.2	12.0	19.2	4:42
30.0	12.0	18.0	4:43
29.0	12.0	17.0	4:44

Degrees cooling, from curve, = 45.0-11.7

= 33.3

Weight of water in globe = 5.75#.

Time of run, 20 min., 1/3 hr.

B.T.U./ hr. = 33.3 × 5.75 × 3 = 574.425

Area, inclosed by curve = 19.0 sq.in.

Length of abscissa = 6.32"

Average ordinate = 3.0" = 23.5 degrees

Thermal constant = 574.425/23.5 = 24.2

Globe # 1. Test # 3.

t_2	t_1	$(t_2 - t_1)$	Time, min.
54.5	15.0	39.5	9:10
51.0	15.0	36.0	9:11
48.0	15.0	33.0	9:12
45.5	15.0	30.5	9:13
43.4	15.0	28.5	9:14
41.5	15.0	26.5	9:15
39.5	.15.0	24.5	9:16
----	15.0	----	9:17
36.8	14.5	22.3	9:18
35.5	14.5	21.0	9:19
34.0	14.5	19.5	9:20
32.8	14.5	18.3	9:21
31.8	14.5	17.3	9:22
30.8	14.5	16.3	9:23
29.8	14.5	15.3	9:24
29.0	14.5	14.5	9:25
28.0	14.5	13.5	9:26
27.2	14.5	12.7	9:27

Degrees cooling, from curve = 45-11.7 = 33.3

Weight of water in globe = 6.1#

Time of run 20 min. 1/3 hr.

B.T.U./ hr. = 33.3 × 6.1 × 3 = 609.39

Area, inclosed by curve = 17.55 sq.in

Length of abscissa = 6.32"

Average ordinate = 2.78" = 22 degrees

Thermal constant = 609.39/22 = 27.7

Globe # 2, Test # 1.				Globe # 2, Test # 2.			
t_2	t_1	(t_2-t_1)	Time	t_2	t_1	(t_2-t_1)	Time
55.2	15.0	40.2	10:25	60.0	14.8	45.2	10:57
53.0	14.8	38.2	10:26	55.8	14.8	41.0	10:58
51.0	14.5	36.5	10:27	52.7	14.8	37.9	10:59
47.5	14.5	33.0	10:28	49.5	14.8	34.7	11:00
45.0	14.5	30.5	10:29	47.0	14.5	32.5	11:01
43.2	14.2	29.0	10:30	44.8	14.5	30.3	11:02
41.5	14.0	27.5	10:31	42.2	14.2	28.0	11:03
39.7	13.8	25.9	10:32	40.2	14.0	26.2	11:04
38.0	13.5	24.5	10:33	38.5	13.8	24.7	11:05
37.0	13.5	23.5	10:34	36.6	13.8	22.7	11:06
35.5	13.2	22.3	10:35	----	----	----	11:07
34.0	13.2	20.8	10:36	33.5	13.5	20.0	11:08
33.0	13.0	20.0	10:37	32.2	13.2	19.0	11:09
31.5	13.0	18.5	10:38	31.0	13.2	17.8	11:10
30.5	13.0	17.5	10:39	29.8	13.2	16.6	11:11
29.8	13.0	16.8	10:40	28.7	13.2	15.5	11:12
28.8	13.0	15.8	10:41	27.8	13.2		
27.9	12.8	15.1	10:42				

Globe # 2. Test # 1.

Degrees cooling, from curve, = 45.-11.6 = 33.4

Weight of water in globe = 6#.

Time of run 20 min., or 1/3 hr.

B.T.U./hr. = 33.4 x 6 x 3 = 601.2

Area, inclosed by curve = 19.35 sq.in.

Length of abscissa = 6.32"

Average ordinate = 3.06" = 24.1 degrees

Thermal constant = 601.2/24.1 = 24.9.

Globe # 2. Test # 2.

Degrees cooling, from curve, = 45-11.8 = 33.2

Weight of water in globe = 6#.

Time of run 20 min., or 1/3 hr.

B.T.U./ hr. = 33.2 x 6 x 3 = 597.6

Area inclosed by curve = 18.5 sq.in

Length of abscissa = 6.32"

Average ordinate = 2.93" = 23.1 degrees

Thermal constant = 597.6/23.1 = 25.8.

Globe # 3 Test 1. Globe # 3 Test 2.

t_2	t_1	(t_2-t_1)	Time	t_2	t_1	(t_2-t_1)	Time
56.5	15.5	41.0	1:57	63.0	17.0	46.0	2:25
53.5	15.5	38.0	1:58	58.5	16.0	41.5	2:26
50.5	15.5	35.0	1:59	----	16.0	----	2:27
48.0	15.0	33.0	1:60	51.0	15.8	34.0	2:28
45.5	15.0	30.5	2:01	48.0	15.5	32.0	2:29
43.0	15.5	27.5	2:02	45.5	15.0	29.5	2:30
41.0	14.5	26.5	2:03	43.0	15.0	27.2	2:31
39.0	14.0	25.0	2:04	40.5	14.5	25.0	2:32
37.5	14.0	23.5	2:05	38.5	14.5	23.5	2:33
36.0	14.0	22.0	2:06	36.5	14.0	21.5	2:34
34.5	13.8	20.7	2:07	34.5	14.0	20.0	2:35
33.0	13.8	19.2	2:08	33.0	14.0	18.5	2:36
31.5	13.5	18.0	2:09	31.5	13.8	17.5	2:37
30.0	13.5	16.5	2:10	30.0	13.5	16.0	2:38
29.0	13.5	15.5	2:11	28.5	13.5	14.5	2:39
28,0	13.5	14.5	2:12	27.5	13.5	13.7	2:40
27.0	13.5	13.5	2:13	26.5	13.5	13.0	2:41

Degrees, Water cooling, from curve = 45-11.7

= 33.3

Weight of water in globe=6#.

Time of run 20 min., 1/3 hr.

B.T.U./ hr. = 33.3 × 6 × 3 = 599.4

Area, inclosed by curve = 18.5 sq. in.

Length of abscissa = 6.32"

Average ordinate = 2.93" = 23 degrees

Thermal constant = 599.4/23 = 26.0

Globe # 3 Test # 2.

Degrees cooling, from curve = 45-11.5 = 33.5

Weight of water in globe = 6#.

Time of run 20 min, 1/3 hr.

B.T.U./ hr. = 33.5 × 6 × 3 = 603

Area, inclosed by curve = 17.8 sq. in.

Length of abscissa = 6.32"

Average ordinate = 2.82" = 22.5 degrees

Thermal constant = 603/22.5 = 26.8

Globe # 4. Test 1.				Globe # 4. Test 2.			
t_2	t_1	$(t_2 - t_1)$	Time	t_2	t_1	$(t_2 - t_1)$	Time
59.0	14.0	45.0	2:51	62.5	14.5	48.0	3:15
55.5	13.5	42.0	2:52	58.5	17.0	41.5	3:16
52.5	13.5	39.0	2:53	55.0	14.5	4o.5	3:17
49.5	13.0	36.5	2:54	52.0	15.5	36.5	3:18
47.0	13.0	34.0	2:55	49.0	14.0	35.0	3:19
44.5	13.0	31.5	2:56	46.0	14.0	32.0	3:20
42.5	13.0	27.5 29.5	2:57	44.0	14.0	30.0	3:21
40.5	13.0	25.0	2:58	41.5	13.5	28.0	3:22
38.0	13.0	23.5	2:59	39.5	13.5	26.0	3:23
36.5	13.0	22.2	3:00	37.5	13.5	24.0	3:24
35.0	12.8	20.2	3:01	36.0	13.0	23.0	3:25
33.0	12.8	19.2	3:02	34.0	1300	21.0	3:26
32.0	12.8	18.0	3:03	32.5	13.0	19.5	3:27
30.5	12.5	16.5	3:04	31.0	13.0	18.0	3:28
29.0	12.5	15.5	3:05	30.0	1[illegible].0	17.0	3:29
28.0	12.5	15.0	3:06	28.5	13.0	15.5	3:30
27.0	12.0		3:07	27.5	12.5	15.0	3:31

Globe # 4. Test # 1.

Degrees cooling, from curve, = 45-11.8 = 33.2

Weight of water in globe = 6#.

Time of run, 20 min, or 1/3 hr.

B.T.U./hr = 33.2 x 6 x 3 = 597.6

Area, inclosed by curve = 18.82 sq.in.

Length of abscissa, = 6.32"

Average ordinate = 2.98" = 23.6 degrees

Thermal constant = 25.3

Globe # 4 Test # 2.

Degrees cooling, from curve, = 45-11.6 = 33.4

Weight of water in globe = 6#.

Time of run, 20 min, 1/3 hr.

B.T.U./ hr = 33.4 x 6 x 3 = 600.2

Area, inclosed by curve = 19.7 sq in.

Length of abscissa = 6.32"

Average ordinate = 3.12" = 24.5 degrees

Thremal constant = 24.5

Globe # 5 Test 1.

t_2	t_1	(t_2-t_1)	Time
67.8	14.8	53.0	3:36
63.8	14.8	49.0	3:37
60.2	14.8	45.4	3:38
57.0	14.8	42.2	3:39
53.8	14.8	39.0	3:40
51.0	14.5	36.5	3:41
48.5	14.5	34.0	3:42
46.0	14.2	31.8	3:43
43.7	13.8	29.9	3:44
41.7	13.5	28.2	3:45
39.5	13.2	26.3	3:46
----	----	----	3:47
36.0	13.2	22.8	3:48
34.7	13.0	21.7	3:49
33.2	13.0	20.2	3:50
31.8	13.0	18.8	3:51
30.5	12.8	17.7	3:52
29.3	12.8	16.5	3:53
28.2	12.8	15.4	3:54
27.2	12.7	14.5	3:55

Globe # 5, Test 2.

t_2	t_1	(t_2-t_1)	Time
63.5	14.0	49.5	4:04
60.0	15.0	45.0	
57.0	14.0	43.0	
54.0	14.0	40.0	
51.5	14.0	37.5	
49.0	14.0	35.0	
47.0	14.0	33.0	
45.0	14.0	31.0	
42.8	14.0	28.8	
41.0	13.8	27.2	
39.1	13.6	25.6	
37.5	13.5	24.0	
36.0	13.2	22.8	
34.5	13.2	21.3	
33.3	13.30	20.3	
32.0	130.	19.0	
31.0	130.	18.0	
30.0	12.8	17.2	
28.8	12.8	16.0	
27.8	12.8	15.0	

Globe # 5. Test # 1.

Degrees cooling, from curve, = 45-11.7 = 33.3

Weight of water in globe = 6#.

Time of run 20 min, or 1/3 hr.

B.T.U./ hr. = 33.3 × 6 × 3 = 599.4

Area, inclosed by curve = 19.3" sq. in.

Length of abscissa = 6.32"

Average ordinate, = 3.05" = 24 degrees

Thermal constant = 599.4/24. = 24.9

Globe # 5. Test # 2.

Degrees cooling, from curve, = 45-11.7 = 33.3

Weight of water in globe = 6#.

Time of run 20 min, 1/3 hr.

B.T.U./ hr. = 33.3 × 6 × 3 = 599.4

Area inclosed by curve = 19.75 sq.in.

Length of abscissa = 6.32"

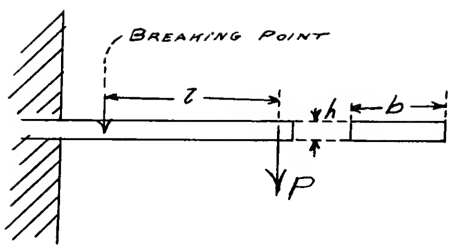
Average ordinate, = 3.12" = 24.5 degrees

Thermal constant = 599.4/24.5 = 24.4

D.

Measurement of Ruptural Strength.

To determine the ruptural strength of the glass, a short strip was loaded as a cantilever beam as shown in the accompanying sketch. The formula for calculating the stress in a beam of this sort is: $M = PI/e$, where M is the maximum bending moment; P is the stress per sq. in.; I is the section moment of inertia; and, e is the distance from the neutral axis to the outermost fiber.



The moment of inertia, I, for this beam of rectangular cross-section, is $1/12\ bh^3$, and

the maximum bending moment is Pl. e, the distance from neutral axis to outermost fiber is 1/2h. Therefore:

$$M = \frac{P\ 1/12\ bh^3}{1/2\ h}$$

The method of proceedure was as follows. The strip of glass was clamped in a wood clamp as shown in the photograph. A bucket was hung on the end of the glass strip, and water poured in the bucket, until the glass broke. The water and bucket were weighed and the breaking point to the point of suspension on the glass measured. This distance, since it is equal to l, times the weight gave the maximum bending moment. The thickness or depth and the width gave the necessary data for substitution in the formula, $M = PI/e$. Results obtained were as follows:

Globe # 1.

W = 5.75# b = .8" h = .09"

$$5.75 \times 2 = p \times .8\ (.09)^2/6$$

p = 10,614 lbs per sq.in.

FIG. 4

Globe # 2.

$W = 7.5 \qquad l = 5.16 \qquad b = 1 \qquad h = .115$

$p = 5.16 \times 7.5 \times 6 / 1(.115)^2$

$p = 17{,}550$ lbs/sq.in.

Globe # 3.

$W = 5.5 \qquad l = 3.875 \qquad b = 1.15 \qquad h = .1$

$p = 3.875 \times 5.5 \times 6 / 1.15\ (.1)^2$

$p = 11{,}120$ lbs./sq.in.

Globe # 4.

$W = 5.0 \qquad l = 4.75 \qquad b = 1.17 \qquad h = .125$

$p = 4.75 \times 5.0 \times 6 / 1.17\ (.125)^2$

$p = 7809$ lbs/sq.in.

Globe # 5.

$W = 14.0 \qquad l = 5.125 \qquad b = 1.125 \qquad h = .15$

$p = 5.125 \times 14.0 \times 6 / 1.125\ (.15)^2$

$p = 17.150$ lbs./sq.in.

PART III.

Results.

Results.

Take the average variables for each globe, and from these values, calculate the constant K for each globe independently. The thickness is taken from the thickness measurements of the ruptural strength test.

Globe # 1.

Heat resistance equals 412.

Average coefficient of expansion $= 7.43 \times 10^{-7}$

Average thermal conductivity $= 25.1$

Ruptural strength $= 10,614$ lbs./sq.in.

Average thickness $= .09''$

$$412 = \frac{K \times 25.1 \times 10,614}{.09 \times 7.43 \times 10^{-7}}$$

$$K \quad 1.03 \times 10^{-10}$$

Globe # 2.

Heat resistance $= 474$

Average coefficient of expansion = 7.11×10^{-7}

Average thermal conductivity = 25.3

Ruptural strength = 17,550 lbs./sq.in.

Average thickness = .115"

$$474 = \frac{K \times 25.3 \times 17.550}{.115 \times 7.11 \times 10^{-7}}$$

$K = 8.73 \times 10^{-9}$

Globe # 3.

Heat resistance = 470

Average coefficient of expansion = 6.02×10^{-7}

Average thermal conductivity = 26.4

Ruptural strength = 11,120 lbs./sq.in.

Average thickness = .1

$$470 = \frac{K \times 26.4 \times 11,120}{.1 \times 6.02 \times 10^{-7}}$$

$K = 9.64 \times 10^{-7}$

Globe # 4.

Heat resistance = 428

Average coefficient of expansion = 6.52×10^{-7}

Average thermal conductivity = 24.9

Ruptural strength = 7,819 lbs./sq.in.

Average thickness = .125"

$$428 = \frac{K \times 24.9 \times 7,809}{.125 \times 6.52 \times 10^{-7}}$$

$$K = 1.8 \times 10^{-10}$$

Globe # 5.

Heat resistance = 447.

Average coefficient of expansion = 7.7×10^{-7}

Average thermal conductivity = 24.65

Average thickness = .15

Ruptural strength = 17,150 lbs./sq.in.

$$447 = \frac{K \times 24.65}{.15 \times 7.7 \times 10^{-7}}$$

$$K = 1.225 \times 10^{-10}$$

PART IV.

Conclusion.

Conclusion

In the solving of the constant K, no attention was paid to the units in which the various variables were expressed. As no special case is dealt with, we left K to be expressed in any desirable way; the main object being to create an expression by means of which inner arc lamps can be compared with reference to the variables mentioned. It is hoped that the report has been successful in determining the heat resisting qualities of the glass, and that it may have some effect on the placing of these globes on a fixed basis.